a pronounced change has occurred in the character of the traffic that is now being carried by many highway routes. While gasoline and rubber shortages have materially reduced the volume of passenger car traffic, wartime transportation demands have caused an increase in bus and truck traffic. Particularly in the case of trucks, more vehicles are using the highways and heavier loads are being carried.

Accordingly, some of our pavements that were never intended to be experimental projects are actually proving to be just that, in the sense that they are undergoing a certain degree of accelerated loading test by reason of this unexpected increase in the volume and weight of wartime truck traffic. Whether due wholly to this over-loading or to a combination of causes, the fact is that some of these pavements are showing signs of structural weakness far ahead of their time, instances having been reported where new concrete pavements built under wartime restrictions have, under wartime traffic, developed serious breakage after having been in service less than six months.

Undoubtedly, there are valuable lessons to be learned from those cases where definite indications of premature failure have occurred. If intelligent conclusions are to be deduced therefrom, it is essential that all pertinent information as to design and construction details as well as subgrade, traffic and climatic conditions be adequately recorded while the data are still fresh and readily obtainable

Any pavement that fails prematurely or acts in an unpredictable manner, if carefully observed so that the causes of its behavior can be intelligently analyzed, is potentially a research project, whether it was originally intended to be such or not. The important thing, therefore, is to realize that such cases that do occur—deplorable as they are because of the economic loss incurred—can be made to serve as a valuable research windfall provided we take advantage of the opportunity of making every effort to determine the full significance of such premature failures and not consider them merely as unfortunate happenings to be charged off as inevitable wartime casualties.

EXPERIMENTS WITH CONTINUOUS REINFORCEMENT IN CONCRETE PAVEMENT—A FIVE-YEAR HISTORY[1]

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and

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SYNOPSIS

In the fall of 1938 a number of experimental sections of reinforced concrete pavement were constructed near Stilesville, Indiana, on U. S. Route No 40 as a cooperative research project Since that time frequent detailed observations have been made to obtain a record of the performance of the various sectrons This report, in presenting a 5-yr history of the behavior of the pavement is divided into 4 parts in which are discussed: (1) periodic elevation changes of the sections, (2) daily, annual and permanent changes in length of the sections; (3) development, distribution and present condition of cracks in the sections; (4) data pertaining to four 500-ft special sections in which weakened-plane joints are spaced at 10-ft intervals

The data obtained during the 5-year period shows that: (1) changes in pavement elevation have been generally small and non-uniform and there is nothing

[1] Condensed. A complete report of the data will be published in *Public Roads*.

to indicate that these changes have affected the length changes and the crack patterns of the sections, (2) excepting the very short sections, daily and annual changes in section length are not directly proportional to length of section; (3) the magnitude of the restraint offered by the subgrade is a function of the time in which a given temperature or moisture change occurs in the pavement, (4) maximum tensile stresses originating from subgrade restraint develop during the late summer and fall; (5) frequency of cracking increases with increase in section length; (6) surface appearance of cracks is a function of width and crack width decreases with increase in amount of longitudinal steel, (7) all of the cracks have remained so tightly closed that they have little if any structural significance.

This is the third report describing a cooperative study of the effects of longitudinal reinforcement in an experimental concrete pavement Preceding reports of this investigation, which is being conducted by the Public Roads Administration and the State Highway Commission of Indiana have presented the scope of the study and the construction of the experimental sections[2], and the developments and trends that became evident during the first 2 years after construction[3]. The present report traces the behavior of the pavement throughout its 5-year life

The reader is referred to the preceding reports for detailed information on the design features, strength data, subgrade characteristics and schedule of observations Briefly, the design covers a range of section lengths varying from 20 to 1310 ft. and a range in the type and amount of longitudinal reinforcement varying from 0 19 in. diameter cold drawn wires (No. 6) at 6-in. centers to 1-in. diameter rail and billet steel bars at 6-in. centers In addition to the regular sections, that is, the sections containing continuously bonded steel, four special 500-ft. sections were included in which weakened-plane joints were spaced at 10-ft. intervals and the bond between the steel and concrete broken for a distance of 18 in on each side of each joint

The experimental pavement was constructed in the fall of 1938 as a part of the transcontinental highway U. S. 40. Since that time frequent detailed observations have been made to obtain a record of the performance of the various sections. This report, in presenting a 5-year history of the behavior of the pavement, is divided into four parts in which are discussed: (1) periodic elevation changes of the regular sections; (2) daily, annual and permanent changes in length of the regular sections, (3) development, distribution and present condition of cracks in the regular sections; and (4) data pertaining to the 500-ft special sections.

[2] "Experiments with Continuous Reinforcements in Concrete Pavements," by Earl C. Sutherland and Sanford W Benham. *Proceedings*, Highway Research Board, Vol 19, 1939, also *Public Roads*, Vol 20, No 11, January 1940.

[3] "Progress in Experiments with Continuous Reinforcement in Concrete Pavements," by Harry D Cashell and Sanford W Benham. *Proceedings*, Highway Research Board, Vol. 20, 1940, also *Public Roads*, Vol 22, No 3, May 1941.

PAVEMENT ELEVATIONS DETERMINED

During the 5-year period three sets of precise elevation measurements have been made over the entire length of the experimental pavement and supplemental measurements have been obtained at more frequent intervals over selected sections.

The data show that the elevation changes of the regular sections have been nonuniform and small in magnitude. At the end of the first year only 7 per cent of the 487 mid-lane locations at which measurements were made showed a change in elevation greater than ±¼ in. when compared with the base elevations established soon after construction of the sections At the end of 5 years observations of representative sections of the pavement indicated that the elevation changes were still relatively small although of greater magnitude and nonuniformity than they were at the end of the first year. During the peak of the severe winter of 1939–40, when the frost had penetrated to a depth of approximately 20 in , increases in elevation were generally within the range of 0 2 to 1 0 in. when compared with the elevations determined the previous fall. Moreover, heaving was, in most instances, greater at the expansion joints than at points elsewhere in the sections Specifically, the average heaving was 0.47 in at 151 expansion joints and 0 33 in. at 185 points elsewhere in the sections.

To graphically summarize, Figure 1 was

prepared from the changes in elevation that were determined from time to time at the centers and at the ends of 24 representative sections, using as a base the elevations established shortly after construction of the sections. Thus the elevation changes shown for the center and for the end of the section are

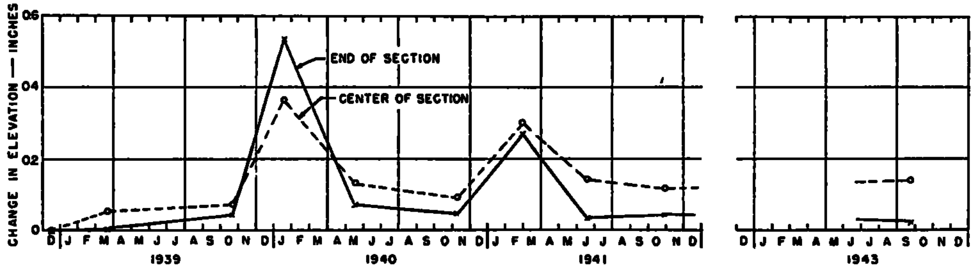

Figure 1. Changes In Elevation Of The Center And End Of Selected Sections With Respect To Time, Average Of 24 Sections

respectively the average change in elevation of the 24 centers and of the 48 ends of the representative sections. This figure not only indicates, for each observation, the positions of the center and end of the average section with respect to their base elevations but suggests the direction and magnitude of warping that was present.

Briefly, the elevation changes for each observation of the average section were small in magnitude, even for the severe winter of 1939–40 and, with the exception of the winter of 1939–40, greater at the center than at the end. This last characteristic seems to indicate a permanent downward warping at the end of the section with respect to its center. On the whole the pavement has raised with respect to the base elevations.

CHANGES IN LENGTHS OF SECTIONS MEASURED

Daily, annual and permanent changes in length were measured at the ends of a number of representative sections. Before presenting the results of this study, attention is called to the fact that the joints were designed to care for a reasonable amount of expansion and contraction of the long sections and, as far as can be ascertained, the length changes of the various sections have been unaffected by confinement at the joints.

In Figure 2 are shown the relationships between section length and change in section length that were found to exist for a daily mid-depth pavement temperature drop of 24 deg. F. and a daily mid-depth pavement temperature rise of 30 deg. F The data for this figure were obtained from 64 sections which cover the range of section length for all sizes of steel for each of the three types of reinforcement. The slope of each lightweight line is in each case the slope computed from the change in

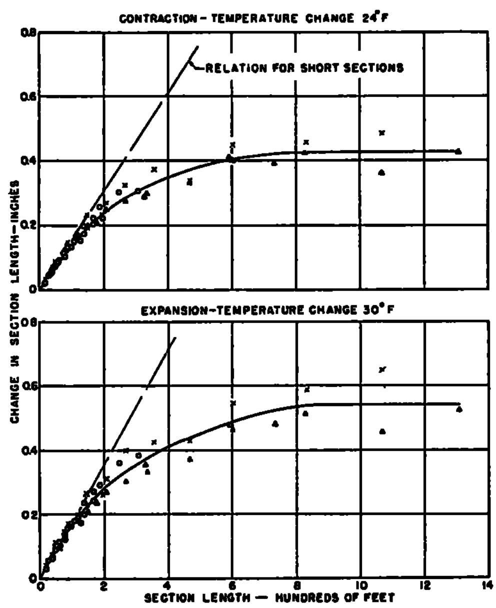

Figure 2. Relation Between Section Length And Daily Change In Length

length of 19 uncracked sections, 20 to 60 ft. in length, and thus represents the relation for short sections that are comparatively free to expand and contract.

It is apparent from this figure that sections up to approximately 75 ft. in length move with as much freedom as the very short sections. The change in length of sections greater than

75 ft. is restrained by the subgrade and this restraint, the effect of which is shown as departure from the relation established from the short sections, increases rapidly as the sections become longer. After 750 to 850 ft. is reached the curves become horizontal thereby indicating that sections whose lengths are greater than 750 to 850 ft have length changes of the same magnitude This condition suggests that the central portion of sections greater than 750 to 850 ft. is completely restrained for quick changes in average concrete temperature.

changes shown are approximately the maximum for the annual cycle. The slopes of the lightweight lines represent respective annual relations determined from 19 uncracked short sections.

It is shown by the four curves of Figure 3 that sections up to approximately 150 ft. in length apparently move with as much freedom as the very short sections. The length changes of sections greater than 150 ft. are restrained by the subgrade and this restraint progressively increases with increase in section length.

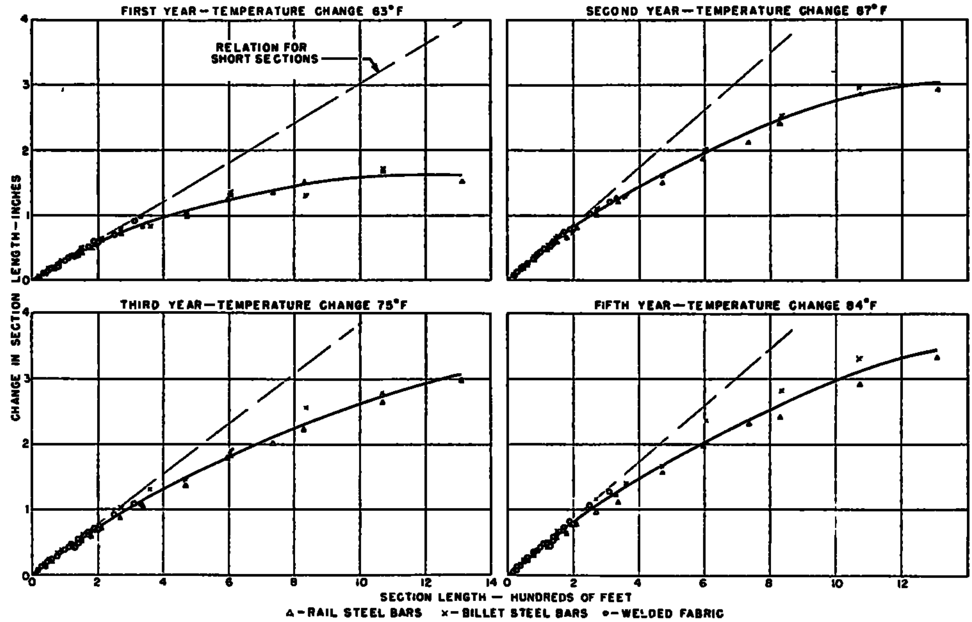

Figure 3. Relation Between Section Length And Annual Expansion

Figure 3 presents the annual changes in length for the first, second, third and fifth years of the life of the pavement The annual change in length of a section was computed from data obtained in the morning of a midwinter day and in the afternoon of a midsummer day and, consequently, includes the length change that occurred between the morning of a winter day and the morning of a summer day plus the daily length change that occurred between the morning and afternoon of the aforementioned summer day. Since an effort was made to obtain these data during the coldest period of winter and the hottest period of summer, the length

The curves of this figure not only indicate the order in which the sections expanded in relation to unrestrained sections, but also show that the sections were able to expand more freely each succeeding year. Specifically, the length change of the 1310-ft section for the first year was only 41 per cent of the expected length change of an unrestrained section This percentage value for the second, third and fifth years respectively increased to 53, 61 and 62 per cent. Thus it appears that the sections encountered less subgrade resistance each successive annual expansion period until, by the end of the third period, a condition of stability was attained

Comparison of the daily and annual length changes of comparable-length sections indicates that the magnitude of the restraint offered by the subgrade is a function of the time in which a given temperature or moisture change occurs in the pavement. Evidence supporting this statement is presented in Figure 4. This figure shows the observed changes in length of the sections that occurred between the morning of a day in February when the mid-depth pavement temperature was 32 deg. F. and the morning of a day in late June of the same year when the mid-depth pavement temperature was 77 deg. F and thus shows the comparative freedom with which sections of all lengths expanded under a slowly developed temperature rise of 45 deg F. These observations were made during the third year of the life of the pavement, at which time stabilization of annual movement had developed.

It is apparent that sections up to 900 ft long expanded as freely as the short sections, while sections greater in length than 900 ft could be restrained but little and may also have expanded freely, dependent upon their state of restraint in February. The exact state of restraint of the various sections is not known at the time of the February observations but it seems safe to conclude that the sections were either unrestrained or restrained in such a manner that they were longer than equivalent-length, free-moving sections. If the first of the two conditions is true and, provided that the segments of the fractured sections do not expand and contract about their individual centers, it follows, therefore, that the sections must change in length an amount equal to the change in length of corresponding free-moving sections in order to be in a free state themselves on the morning of the June day If the second condition of restraint is true, then the sections to be free in June need change in length less than the length change of corresponding free-moving sections by the amount that they were unduly extended at the time of the initial measurements

The manner in which the sections expanded from February to June suggests that subgrade resistance did not accumulate from winter to summer and, as a consequence, residual compression was probably nonexistent in the sections of the lengths included in this study on the morning of the June day when the pavement temperature was 77 deg. F. As a matter of fact, evidence indicates that a slight amount of tension was present in sections ranging between 200 and 900 ft. in length.

In the light of the knowledge gained in this study, it seems logical that as summer advances and the mean pavement temperature gradually rises the sections expand to their maximum annual length without developing appreciable residual compression. Then in the late summer or early fall the comparatively large, sudden drops in temperature cause comparatively large direct tensile stresses to be

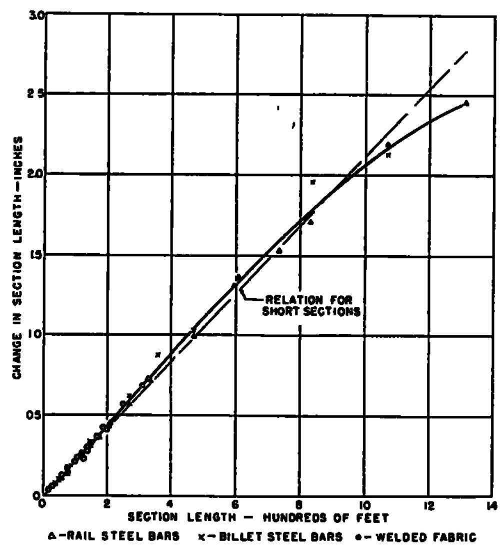

Figure 4. Relation Between Section Length And Change in Length—From The Morning Of a Winter Day To The Morning of a Summer Day Of The Same Year. Mean Pavement Temperature Change of 45°F.

developed in the sections, larger probably than at any other period during the year

To evaluate growth or permanent change in length, measurements are being made every February and August at the ends of a number of selected sections The February observations are obtained when the mid-depth pavement temperature is 32 deg. F. and the August observations when the mid-depth pavement temperature is 92 deg. F The effect of moisture variations is reduced to a minimum since the moisture content of the pavement remains virtually constant during February and August, at which times the annual maximum and minimum quantities of absorbed moisture are respectively present in the concrete. The results of these observations are shown in Figure 5, plotted with respect to the initial set of measurements obtained in February 1939.

Considering the sections in order of length it is observed that the short, uncracked sections, which comprise 340 ft. of pavement and are free to expand and contract, show no definite indication of a permanent change in length either for the February values (circles) or for the August values (crosses). The behavior of the 140-ft. section practically coincides with that of the short sections The 335-, 600-, 1070- and 1310-ft. sections show a progressive increase in expanded lengths each August but every succeeding February they return so closely to their base length of February 1939 that, up to the present time, permanent growth is not manifested. The fact that these sections show progressive increase in their lengths each annual expansion period merely substantiates previous evidence that restraint offered by the subgrade becomes less from year to year. In view of the many transverse cracks that have occurred in the long sections, the manner in which these sections return to their base length is rather surprising. This phenomenon not only implies that the initial widths of the cracks are extremely fine but also demonstrates that the steel reinforcement prevents progressive opening of the cracks.

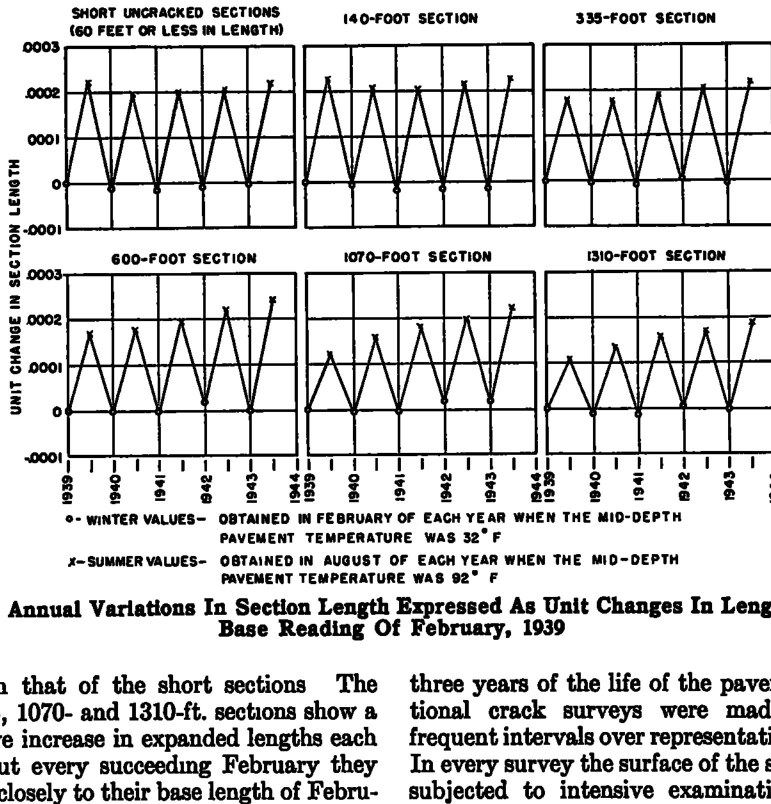

Figure 5. Annual Variations In Section Length Expressed As Unit Changes In Length From A Base Reading Of February, 1939

CRACK FORMATION OBSERVED

Four crack surveys have been made over the full length of the experimental pavement. The first survey was made shortly after the sections were placed and subsequent surveys were conducted at the end of the first, third and fifth years. Furthermore, during the first three years of the life of the pavement, additional crack surveys were made at more frequent intervals over representative sections. In every survey the surface of the sections was subjected to intensive examination for the purpose of detecting all cracks that were visible to the eye.

Figure 6, traced from the crack survey sheets, pictures the number and position of the cracks that have developed in typical sections during the 5-yr life of the pavement This figure includes data obtained in nine surveys over short sections containing three different weights of wire fabric reinforcement, intermediate-length sections reinforced with ½-in diameter steel and long sections reinforced with 1-in diameter steel.

It is indicated that short sections are comparatively free of cracks. Specifically, at the end of five years only 20 per cent of the 154 short sections whose lengths are 120 ft. or less were found to be cracked. However, as the sections increase in length cracking becomes more prevalent until in the central portion of long sections the crack interval is frequently less than 2 ft. It is also observed that the cracks are virtually transverse in character but, in many instances, are not continuous across both lanes, being offset slightly at the longitudinal joint. Moreover, longitudinal cracking has not developed in any of the sections.

Referring to the present width and condition, of the cracks at the pavement's upper surface it was observed that those in the short sections containing the relatively light weights of welded fabric are typical of the cracks found in comparable reinforced pavement in use elsewhere today. Raveling and rounding of the edges of the cracks have, in extreme instances, been sufficient to produce a surface width of 0.2 in. By contrast, cracks in the intermediate-length sections reinforced with ½-in. diameter steel bars and the heavier welded fabric present a better surface appearance. Raveling is not as pronounced and consequently the surface width of these cracks has been greatly reduced. In the long sections reinforced with ¾- and 1-in rail and billet steel bars the cracks are extremely fine, being discernible only on close inspection. Raveling

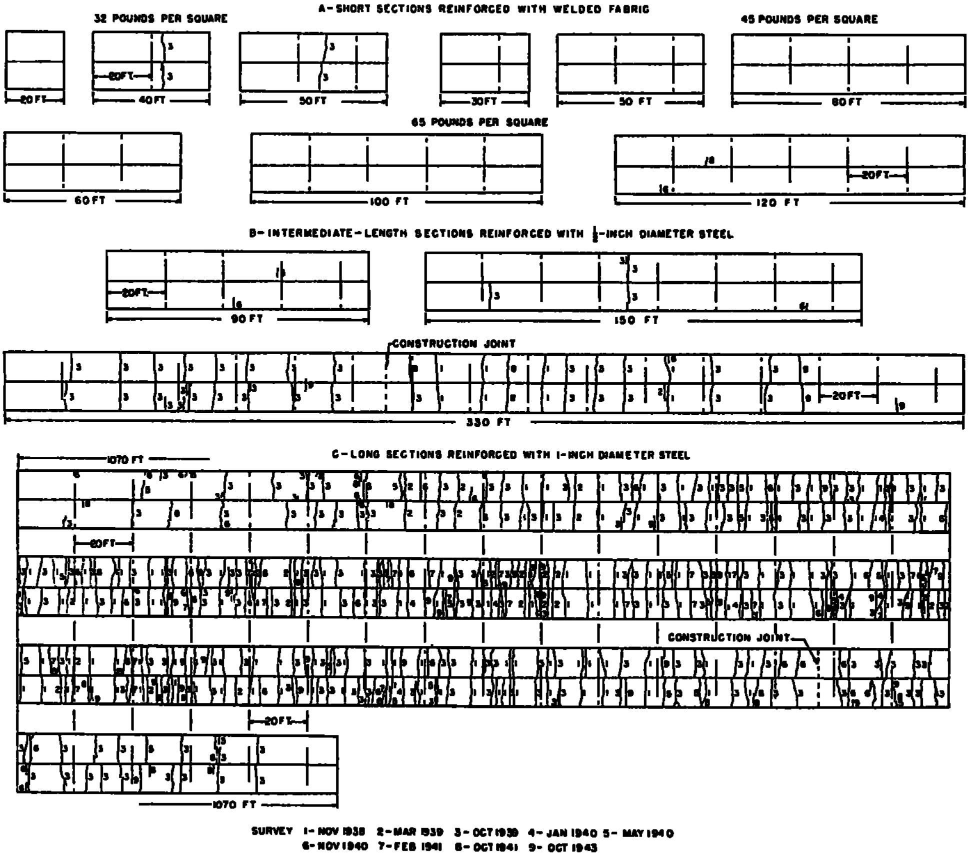

Figure 6. Typical Formation Of Cracks During The First Five Years Of Pavement Life—Sections Placed September–October, 1938

and rounding of the edges of these cracks are practically microscopic At present there is no evidence of disintegration of the concrete in the immediate vicinity of any of the cracks; nor have the cracks opened sufficiently to indicate failure of the steel crossing them

Examination of the cracks at the edge face of the pavement revealed that the crack width as observed at the pavement's upper surface may be many times the actual width of the crack that exists a short distance below the surface. This condition was found to be especially true in the lightly reinforced sections. At the end of five years, a few crack-width measurements were made with a special measuring microscope at the edge face of pavement where the crack widths appeared to be unaffected by chipping or raveling. The widths thus determined were found to be 0.009, 0 003 and 0.002

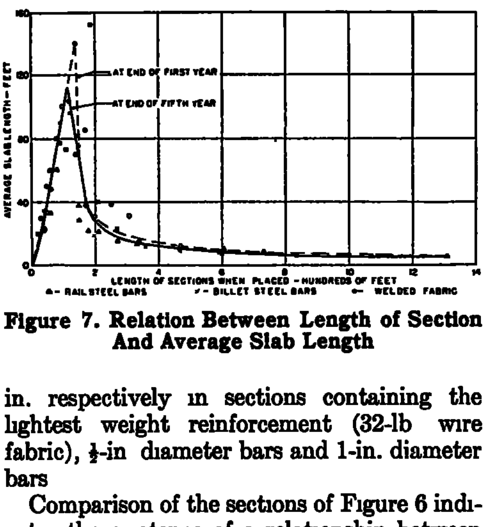

Figure 7. Relation Between Length of Section And Average Slab Length

in. respectively in sections containing the lightest weight reinforcement (32-lb wire fabric), ½-in diameter bars and 1-in. diameter bars

Comparison of the sections of Figure 6 indicates the existence of a relationship between length of section and average slab length (average distance between transverse cracks). The relationships that obtained at the end of the first and fifth years of the life of the pavement are shown in Figure 7. The data for all of the experimental sections for each of the three types of reinforcement are included in this figure, each value being the average of either 2, 4 or 6 sections. For clarity in presentation, the individual values that determine the first year relation are omitted from the graph

The points defining the 5-yr. curve are somewhat erratic for sections up to approximately 300 ft long This effect is statistical, being caused by the small amount of cracking and the fact that each value is based upon a limited number of sections Nevertheless, it is believed that the curves adequately indicate the relations between length of section and average slab length.

At the end of the first year very little cracking was found in sections having lengths of 140 ft. or less In sections longer than 140 ft. cracking occurred and, as evidenced by the curve, the average slab length decreased rapidly as the sections increased from 140 to approximately 250 ft. in length In sections having lengths greater than 250 ft the average slab length gradually decreased, approaching a constant value for the longer sections. For example, the average distance between transverse cracks for a 250-, 800- and a 1310-ft. section was respectively about 23, 8.5 and 7 ft By the end of five years the longest average slab length as established by the curve had been reduced to 112 ft and the average distance between cracks for the 250-, 800- and 1310-ft. section had been respectively reduced to 20, 6 5 and 5 ft.

In Figure 8 is shown the distribution of cracking for representative sections expressed as the number of cracks per 50-ft. of section length It is observed that· (1) the number of cracks per 50-ft. increment increases from a minimum value at the end of a section to a maximum value in the central area in a normal frequency distribution; and (2) the maximum central area values of the sections, included in the figure, progressively increase with increase in section length.

Continuing the discussion of the latter relation of the preceding paragraph, it was found that the average distance between cracks for the central 400 ft. of a 1310-ft. section (not shown in figure) was equal to that of a corresponding length of the 1070-ft section. Because of this similarity it might be suggested that the central crack pattern of these sections is representative of the cracking that would develop in even longer similarly reinforced sections or, perhaps, reinforced pavement of infinite length. However, it must be kept in mind that although the central portion of the 1070- and the 1310-ft. sections may be completely restrained for daily and short-term temperature drops, considerable freedom of movement is permitted these areas during an annual temperature drop; whereas, comparable freedom of annual movement would not be expected to exist in continuously reinforced pavement of infinite length.

The manner in which cracking developed in the sections during various periods is also shown in Figure 8. The first period shows the magnitude and distribution of cracking that appeared within approximately one month after construction of the experimental sections.

The second period covers the first winter after construction. The survey at the end of the winter showed that cracking did not appear in sections less than 270 ft. long and only a small amount, spottily distributed, developed in sections having lengths equal to or greater than 270 feet. The absence of cracking during this period has two important implications, namely: (1) the nonuniform changes in pavement elevation caused by frost penetration of

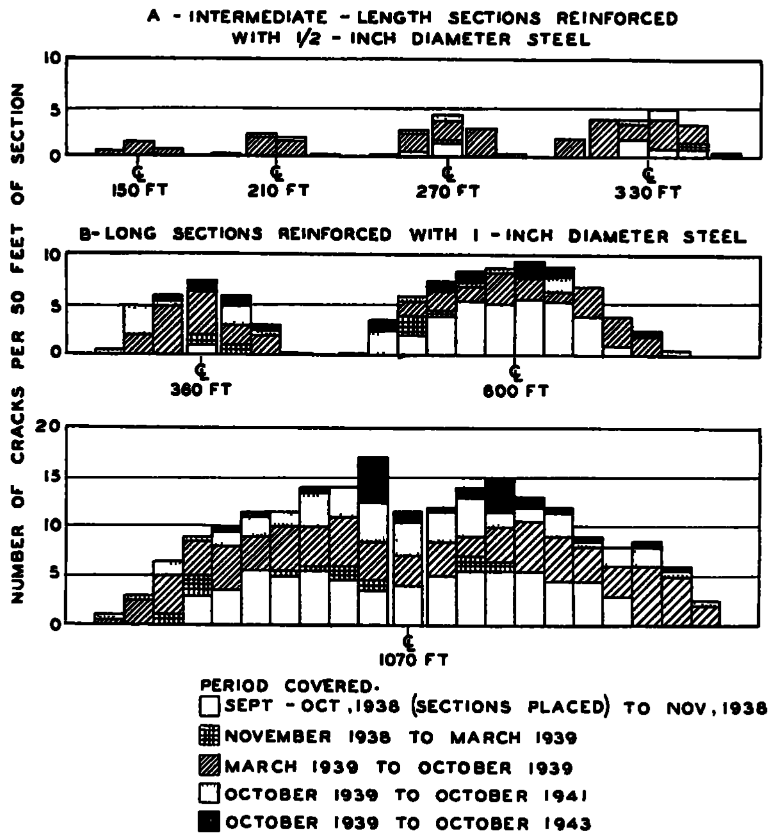

Figure 8. Distribution of Cumulative Cracking Per 50 Feet Of Section Length—First 5 Years Of Pavement Life

During this time cracking did not develop in sections having lengths less than 270 ft and only a limited amount occurred in the central portion of the 270-, 330- and 360-ft sections while considerable cracking developed at some distance from the ends of the 600- and 1070-ft. sections Tensile stresses originating from resistance offered by the subgrade were probably the primary cause of cracking during this period

the subgrade apparently had little if any influence upon cracking, and (2) tensile stresses originating from subgrade resistance evidently were less during the winter period than they were during the preceding fall. This latter implication is in support of the conclusion derived from the data of Figure 4

In the period between late March and October of the first year, considerable change occurred in all of the sections. In fact, a large percentage of the cracks now present in sections having lengths less than 360 ft. and in the end areas of longer sections developed sometime during this period The cracking that appeared in short sections and in the end areas of intermediate-length and long sections was probably caused primarily by warping stresses and apparently occurred during the late spring and early summer when warping stresses are high The cracking that developed at some distance from the ends of the intermediate-length and long sections was probably caused by the stress combinations existent in late summer and early fall when the sections were contracting after having attained their maximum annual unrestrained lengths.

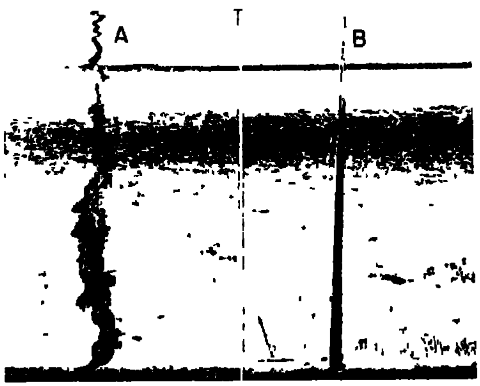

Figure 9. Present Condition Of: A, Typical Crack Over Submerged Parting Strip; B, Typical Weakened-Plane Joint With Surface Groove

During the fourth period, which covers the second and third years after construction, the greatest concentration of cracking developed in the interior portion of the 1070-ft section. The fifth period includes the fourth and fifth years after construction and the small amount of cracking that appeared during this period signifies a great reduction in the rate of cracking.

It will be noted that the symmetry of cracking observed in the various sections is indicative of structural uniformity

In connection with the study of cracking, an opportunity has been afforded to observe the effect of traffic on the development and condition of the cracks It will be recalled that the experimental 2-lane pavement is one half of a divided highway, consequently, the right-hand lane carries the greater number of vehicles and practically all of the heavy trucks, the left-hand lane being used largely for passing. At the end of the first year 51 per cent of all cracks that had occurred in the full length of the pavement appeared in the right-hand lane. This percentage value at the end of the third and fifth years had increased to 52 and 53 per cent respectively. Thus, it appears that repetition of traffic loads is exerting a slight but only a slight influence on the development of transverse cracks. Since a large percentage of the cracks appeared during the first year, the effect of traffic repetition on subsequent cracking is more pronounced than is indicated by the preceding percentage values. Specifically, of the cracks that occurred during the second and third years after construction, 57 per cent appeared in the right-hand lane This value was increased to 62 per cent for the cracks that occurred during the fourth and fifth year period Traffic has had an effect on the surface condition of the cracks also, those in the right-hand lane having raveled and rounded slightly more than companion cracks in the left-hand lane. This effect is almost imperceptible for cracks in sections reinforced with ¾ and 1-in steel bars but is quite conspicuous in the lightly reinforced sections.

SECTIONS CONTAINING WEAKENED-PLANE JOINTS

The four special 500-ft. sections containing plane-of-weakness joints at 10-ft intervals have been subjected to the same intensive study as have the regular sections However, in this condensed report only the surface condition of these joints will be discussed

Figure 9-A shows the present appearance of a crack which is typical of those that formed over the submerged grooves. These cracks are meandering in character and have opened slightly with the result that raveling and chipping of the edges is quite obvious at the pavement's surface This condition developed rapidly after the cracks formed and during the last 2 or 3 years further impairment has been very gradual.

The present appearance of a typical weakened-plane joint of the surface groove type is shown in Figure 9-B. At the end of five years the condition of these joints is so remarkably good that resealing or maintenance has not been necessary.

Although relative roughness comparisons of the pavement's surface were not made instrumentally at the end of five years, the riding quality of the sections containing both the submerged and surface type weakened-plane joints has continued to remain very satisfactory. This characteristic belies the surface appearance of the cracks that formed over the submerged parting strips.

SUMMARY

In this report the performance of the experimental sections has been traced through five years.

It has been shown that: (1) changes in pavement elevation have been small and there is nothing to indicate that these changes have affected the relationships established in this report; (2) excepting the very short sections, daily and annual changes in section length are not directly proportional to length of section; (3) the magnitude of the restraint offered by the subgrade is a function of the time in which a given temperature or moisture change occurs in the pavement; (4) maximum tensile stresses originating from subgrade restraint develop in the late summer and fall; (5) frequency of cracking increases with increase in section length; (6) surface appearance of cracks is a function of width and crack width decreases with increase in amount of longitudinal steel; (7) all of the cracks have remained so tightly closed that they have little if any structural significance.

RIGID TYPE PAVEMENT JOINTS AND JOINT SPACING

By H. F. Clemmer, *Engineer of Materials, District of Columbia*

SYNOPSIS

The Highway Department of the District of Columbia has investigated the movement of concrete pavements and ascertained it to approximate that generally assumed in theoretical design. It has been found that the shrinkage of the concrete in setting will provide sufficient expansion space for pavements constructed during normal summer conditions, and that if planes of weakness are constructed at approximately 15 ft intervals a certain degree of dowelling across the joints will be maintained

Experiment and experience over ten years have proved that the division of concrete bases into slabs 12½ ft. long will provide definite control of cracking in sheet asphalt surfaces; the movement at any one joint being so slight as to be absorbed by the resilience of the bituminous surface.

The Highway Department of the District of Columbia recommends the construction of reasonably short slabs, and when available the use of well distributed reinforcement, tie bars at all construction joints and load transfers across all transverse expansion and contraction joints.

The rigid wartime curtailment in the use of critical materials, particularly steel, has required engineers to give particular consideration to design and construction methods to insure satisfactory and durable pavements when constructed with unrestricted materials Not only has it been necessary to design and construct pavements without mesh or bar mat reinforcement, but it has been necessary to design the joints without load transfers or tie bars. This has made the use and construction of joints in concrete pavements and concrete pavement bases one of the most important of the design problems The study given this problem and reports of experiments and field surveys have brought out many facts applicable to the use of joints for postwar design when steel and other critical materials will again be available

Concrete changes in volume with changes